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Recent Results in Charmless Hadronic B Decays from BABAR

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We report results from five analyses based on data taken with the *BABAR* detector at the PEP-II asymmetric e^+e^- collider. Included are branching fraction measurements for many B-meson decays involving η, η', ω, ϕ or a_0 mesons and the final state $K^0_S\pi^+\pi^-$, and a full angular analysis of the decay $B^0 \to \phi K^{*0}$.

1 Introduction

Many interesting new results from *BABAR* for charmless hadronic B decays were presented previously at the Electroweak session of the XXXIXth Rencontres de Moriond. For new measurements of sin2β from four final states (ϕK^0, $K^+K^-K^0_S$, $\pi^0 K^0_S$, $f_0 K^0_S$), see the writeup by Marc Verderi. Also a new preliminary result for the decay $B^0 \to \rho^+\rho^-$, with a measurement of the CKM angle α was presented in a talk by Lydia Roos. Finally a measurement of the time-dependent asymmetry of the decay $B^0 \to \pi^0 K^0_S\gamma$ was shown by Eugenio Paoloni. With adequate data, the latter mode can provide interesting constraints on new physics.

In this paper I will report on five other new analyses of charmless hadronic B decays. The first involves B decays to $\eta^{(\prime)}K^*$, $\eta^{(\prime)}\rho$, $\eta^{(\prime)}\pi^0$, $\omega\pi^0$, and $\phi\pi^0$.[1] Substantial signals are seen for $B \to \eta K^*$ and limits are provided for the other modes. The decay $B \to \eta' K^*$ is particularly interesting since it provides limits on a flavor-singlet amplitude.[2,3] The second analysis searches for eight isoscalar final states.[4] In addition to the interest in observing signals should the branching fractions be large enough, these channels are interesting because they can provide constraints on the expected value of sin2β for the modes $B^0 \to \eta' K^0$ and $B^0 \to \phi K^0$.[5,6] These channels provide constraints on the size of the color-suppressed tree amplitudes for these penguin-dominated channels. The third analysis involves a search for B decays to the scalar a_0 meson accompanied by pions or kaons. Little is known about decays involving scalars. The fourth analysis is a fairly precise measurement of the decay $B \to K^0_S\pi^+\pi^-$. The last analysis measures the polarization and potential CP-violating terms in the full angular analysis of the decay $B \to \phi K^{*0}$.

2 Datasets and analysis details

The results presented here are based on data collected with the *BABAR* detector[7] at the PEP-II asymmetric e^+e^- collider located at the Stanford Linear Accelerator Center. Most analyses

use a sample of 89 million $B\overline{B}$ pairs, recorded at the $\Upsilon(4S)$ resonance (center-of-mass energy $\sqrt{s} = 10.58$ GeV). The $B \to \phi K^{*0}$ analysis uses a sample of 124 million $B\overline{B}$ pairs.

A B-meson candidate is characterized kinematically by the energy-substituted mass $m_{\rm ES}$ and by the energy difference ΔE, defined as

$$m_{\rm ES} = \sqrt{\frac{1}{4}s - \mathbf{p}_B^{*2}} \qquad \text{and} \tag{1}$$

$$\Delta E = E_B^* - \frac{1}{2}\sqrt{s}\,, \tag{2}$$

where $(E_B, \mathbf{p}_B)$ is the B-candidate four vector and s is the square of the invariant mass of the electron-positron system; the asterisk denotes the value in the $\Upsilon(4S)$ frame. All analyses use these two quantities in unbinned maximum-likelihood fits which also have invariant masses of quasi-two-body resonances in the final states and a Fisher discriminant that is sensitive to event shape.

3 Measurements of $\eta^{(\prime)}K^*$ and related decays

We have searched for the B decays to $\eta^{(\prime)}K^*$, $\eta^{(\prime)}\rho$, $\eta^{(\prime)}\pi^0$, $\omega\pi^0$, and $\phi\pi^0$. We find a substantial signal for both charge states of the $B \to \eta K^*$ decay as shown in the projection plots in Fig. 1. These results are tabulated in Table 1 along with previous results for the $\eta^{(\prime)}K$ and $\eta^{(\prime)}\pi$ decays. Thus we have completed the measurement of the four $(\eta, \eta')(K, K^*)$ final states with a sensitivity in the branching fraction of a few times 10^{-6}. We find no significant signal for $B \to \eta' K^*$; the 90% C.L. upper limit is not yet precise enough to determine whether a flavor-singlet component is present for this decay, though we do restrict the size of such a contribution. See Ref. 2 and references therein for a discussion of this issue. We also have evidence for the decay $B^+ \to \eta\rho^+$ with a significance of 3.5σ.

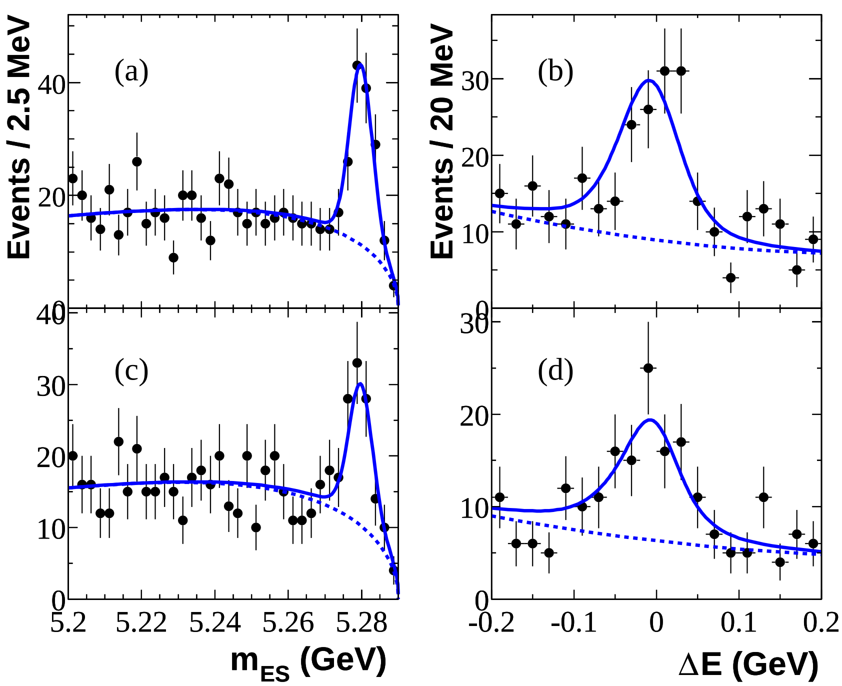

Figure 1: Projections of the B-candidate $m_{\rm ES}$ and ΔE distributions for (a),(b) $B^0 \to \eta K^{*0}$ and (c),(d) $B^+ \to \eta K^{*+}$. Not all events are shown since these plots are made with a requirement on the likelihood.

Table 1: We show the significance $\mathcal{S}(\sigma)$ (including systematic errors), fit branching fractions $\mathcal{B}$, 90% C.L. upper limits, and charge asymmetries for the 12 new measurements as well as six related measurements (above the line) that were published recently.[8,9]

Mode	$\mathcal{S}(\sigma)$	$\mathcal{B}(10^{-6})$	UL (10^{-6})	$\mathcal{A}_{ch}$
$B^+ \to \eta' K^+$	>10	76.9 ± 3.5		0.037 ± 0.045
$B^0 \to \eta' K^0$	>10	60.6 ± 5.6		
$B^+ \to \eta\pi^+$	7.9	$5.3 \pm 1.0 \pm 0.3$		$-0.44 \pm 0.18 \pm 0.01$
$B^+ \to \eta K^+$	6.1	$3.4 \pm 0.8 \pm 0.2$		$-0.52 \pm 0.24 \pm 0.01$
$B^0 \to \eta K^0$	3.3	$2.9 \pm 1.0 \pm 0.2$	<5.2	
$B^+ \to \eta'\pi^+$	3.4	$2.7 \pm 1.2 \pm 0.3$	<4.5	
$B^+ \to \eta K^{*+}$	9	$25.6 \pm 4.0 \pm 2.4$		$+0.13 \pm 0.14 \pm 0.02$
$B^0 \to \eta K^{*0}$	11	$18.6 \pm 2.3 \pm 1.2$		$+0.02 \pm 0.11 \pm 0.02$
$B^+ \to \eta\rho^+$	3.5	$9.2 \pm 3.4 \pm 1.0$	<14	
$B^0 \to \eta\rho^0$	–	$-1.1^{+0.7}_{-0.9} \pm 0.4$	<1.5	
$B^0 \to \eta\pi^0$	0.8	$0.7^{+1.1}_{-0.9} \pm 0.3$	<2.5	
$B^+ \to \eta' K^{*+}$	1.9	$6.3^{+4.6}_{-3.6} \pm 1.8$	<14	
$B^0 \to \eta' K^{*0}$	2.1	$4.1^{+2.1}_{-1.8} \pm 1.2$	<7.6	
$B^+ \to \eta'\rho^+$	2.6	$12.9^{+6.2}_{-5.5} \pm 2.0$	<22	
$B^0 \to \eta'\rho^0$	0.5	$0.8^{+1.7}_{-1.2} \pm 0.9$	<4.3	
$B^0 \to \eta'\pi^0$	0.7	$1.0^{+1.4}_{-1.0} \pm 0.8$	<3.7	
$B^0 \to \omega\pi^0$	–	$-0.6^{+0.7}_{-0.5} \pm 0.2$	<1.2	
$B^0 \to \phi\pi^0$	0.7	$0.2^{+0.4}_{-0.3} \pm 0.1$	<1.0	

4 Search for isoscalar charmless decays

We have searched for eight isoscalar charmless decays. These decays are particularly interesting because they can provide constraints on the expected value of sin2β for the modes $B^0 \to \eta' K^0$ and $B^0 \to \phi K^0$.[5,6] Results are summarized in Table 2. The 4.3σ signal in $B^0 \to \eta\omega$ is unexpected and may be a fluctuation; more data will be required to see if this is interesting. The limits on all of these modes have improved the understanding of the expected value of sin2β for $B^0 \to \eta' K^0$ so that the model-independent precision is now 0.10. [6] This is an improvement of about a factor of five on the previous limits.[5]

Table 2: Significance $\mathcal{S}(\sigma)$ (including systematic uncertainties), measured branching fraction $\mathcal{B}$, and 90% C.L. upper limits (UL) from this and previous measurements by CLEO.

Mode	S(σ)	$\mathcal{B}(10^{-6})$	UL (10^{-6})	CLEO UL (10^{-6}) [10]
$B^0 \to \eta\eta$	0.0	$-0.9^{+1.6}_{-1.4} \pm 0.7$	<2.8	<18
$B^0 \to \eta\eta'$	0.3	$0.6^{+2.1}_{-1.7} \pm 1.1$	<4.6	<27
$B^0 \to \eta'\eta'$	0.4	$1.7^{+4.8}_{-3.7} \pm 0.6$	<10	<47
$B^0 \to \eta\omega$	4.3	$4.0^{+1.3}_{-1.2} \pm 0.4$	<6.2	<12
$B^0 \to \eta'\omega$	0.0	$-0.2^{+1.3}_{-0.9} \pm 0.4$	<2.8	<60
$B^0 \to \eta\phi$	0.0	$-1.4^{+0.7}_{-0.4} \pm 0.2$	<1.0	<9
$B^0 \to \eta'\phi$	0.8	$1.5^{+1.8}_{-1.5} \pm 0.4$	<4.5	<31
$B^0 \to \phi\phi$	0.3	$0.3^{+0.7}_{-0.4} \pm 0.1$	<1.5	<12

5 Search for B decays involving a_0 mesons

Very little is known about charmless B decays with a scalar meson in the final state. There are also few predictions for these decays. [11,12] We have searched for quasi-two-body B decays with an a_0 meson and a pion or kaon. This follows a previous preliminary search where evidence for the decay $B^0 \to a_0^- \pi^+$ was found.[13] The results of the present search are summarized in Table 3. We do not confirm the previous result which was obtained with one-quarter of this data sample. The difference appears to be a fluctuation. We provide preliminary upper limits on this and five related decay channels. This are the first measurements for these decays and seem to rule out the largest predictions for the $B^- \to a_0^- K^0$ decay from one recent paper.[12]

Table 3: Significance $\mathcal{S}(\sigma)$ (including systematic uncertainties), measured branching fraction $\mathcal{B}$, and 90% C.L. upper limits (UL) for B decays involving a_0 mesons.

Mode	$\mathcal{S}(\sigma)$	$\mathcal{B}(10^{-6})$	UL (10^{-6})
$B^0 \to a_0^- \pi^+$	2.0	$2.8^{+1.5}_{-1.3} \pm 0.7$	< 5.1
$B^0 \to a_0^- K^+$	0.4	$0.4^{+1.0}_{-0.8} \pm 0.2$	< 2.1
$B^- \to a_0^- K^0$	0.6	$-1.5^{+2.4}_{-1.8} \pm 0.8$	< 3.9
$B^+ \to a_0^0 \pi^+$	1.9	$3.6^{+2.1}_{-1.9} \pm 0.8$	< 6.7
$B^+ \to a_0^0 K^+$	0.0	$-3.7^{+1.6}_{-1.3} \pm 0.5$	< 1.8
$B^0 \to a_0^0 K^0$	1.0	$2.8^{+3.1}_{-2.4} \pm 1.1$	< 7.8

6 Measurement of the branching fraction for the decay $B \to K^0 \pi^+ \pi^-$

We measure the branching fraction of the decay $B \to K^0 \pi^+ \pi^-$. Corrections are made for the efficiency variation across the Dalitz plot. From 310 ± 27 signal events, we measure $\mathcal{B}(B \to K^0 \pi^+ \pi^-) = 43.8 \pm 3.8 \pm 3.4 \times 10^{-6}$. This is in good agreement with, but more precise than, previous results. [14] An analysis of the Dalitz plot structure is in progress.

7 Measurement of polarization and CP-violating terms in a full angular analysis of $B \to \phi K^{*0}$

We present a full angular analysis of the decay $B \to \phi K^{*0}$. The angular distribution of the $B \to \phi K^*$ decay products can be expressed in the helicity representation with $\mathcal{H}_i = \cos\theta_i$ and Φ, where θ_i is the angle between the direction of one of the vector meson daughters ($i = 1$ for the $K^* \to K\pi$, $i = 2$ for the $\phi \to K\overline{K}$) and the direction opposite the B in the resonance rest frame, and Φ is the angle between the two resonance decay planes. The differential decay width has three complex amplitudes A_λ for the vector meson helicity $\lambda = 0$ or ± 1.[15,16] The decay width can be written, in terms of $A_\parallel = (A_+ + A_-)/\sqrt{2}$, and $A_\perp = (A_+ - A_-)/\sqrt{2}$, as

$$\frac{8\pi}{9\Gamma} \cdot \frac{d^3\Gamma}{d\mathcal{H}_1 d\mathcal{H}_2 d\Phi} = \frac{1}{|A_0|^2 + |A_\parallel|^2 + |A_\perp|^2} \times \Big[|A_0|^2 \mathcal{H}_1^2 \mathcal{H}_2^2 + \frac{1}{4}(|A_\parallel|^2 + |A_\perp|^2)(1-\mathcal{H}_1^2)(1-\mathcal{H}_2^2)$$
$$+ \frac{1}{4}(|A_\parallel|^2 - |A_\perp|^2)(1-\mathcal{H}_1^2)(1-\mathcal{H}_2^2)\cos 2\Phi \; - \mathrm{Im}(A_\perp A_\parallel^*)(1-\mathcal{H}_1^2)(1-\mathcal{H}_2^2)\sin 2\Phi$$
$$+ \sqrt{2}\mathrm{Re}(A_\parallel A_0^*)\sqrt{1-\mathcal{H}_1^2}\,\mathcal{H}_1\sqrt{1-\mathcal{H}_2^2}\,\mathcal{H}_2\cos\Phi \; - \; \sqrt{2}\mathrm{Im}(A_\perp A_0^*)\sqrt{1-\mathcal{H}_1^2}\,\mathcal{H}_1\sqrt{1-\mathcal{H}_2^2}\,\mathcal{H}_2\sin\Phi \Big].$$

We measure the polarization parameters $f_L = |A_0|^2/\Sigma|A_\lambda|^2$, $f_\perp = |A_\perp|^2/\Sigma|A_\lambda|^2$, $\phi_\parallel = \arg(A_\parallel/A_0)$, and $\phi_\perp = \arg(A_\perp/A_0)$. We also allow for CP-violating differences between the $\overline{B}^0$

Table 4: We show results for the ten primary signal fit parameters and the secondary triple-product asymmetries. All results include systematic errors quoted last. The dominant correlations coefficients are also shown.

Fit param.	Fit result	Corr.	Fit param.	Fit result	Corr.
$n_{\rm sig}$ (events)	$129 \pm 14 \pm 9$		$\mathcal{A}_{CP}$	$-0.12 \pm 0.10 \pm 0.03$	
f_L	$0.52 \pm 0.07 \pm 0.02$	$\}$ -52%	$\mathcal{A}^0_{CP}$	$-0.02 \pm 0.12 \pm 0.01$	$\}$ -52%
$f_\perp$	$0.27 \pm 0.07 \pm 0.02$		$\mathcal{A}^\perp_{CP}$	$-0.10^{+0.25}_{-0.27} \pm 0.04$	
$\phi_\parallel$ (rad)	$2.63^{+0.24}_{-0.23} \pm 0.04$	$\}$ $+59\%$	$\Delta\phi_\parallel$ (rad)	$0.38^{+0.23}_{-0.24} \pm 0.04$	$\}$ $+59\%$
$\phi_\perp$ (rad)	$2.71^{+0.22}_{-0.24} \pm 0.03$		$\Delta\phi_\perp$ (rad)	$0.30^{+0.24}_{-0.22} \pm 0.03$	
$\mathcal{A}^\parallel_T$	$+0.02 \pm 0.05 \pm 0.01$		$\mathcal{A}^0_T$	$+0.11 \pm 0.07 \pm 0.01$	

($Q = +1$) and the B^0 ($Q = -1$) decay amplitudes, where the flavor sign Q is determined in the self-tagging final state with a $\overline{K}^*$ or K^*:

$$n^Q_{\rm sig} = n_{\rm sig}(1 + Q\mathcal{A}_{CP})/2; \quad f^Q_L = f_L(1 + Q\mathcal{A}^0_{CP}); \quad f^Q_\perp = f_\perp(1 + Q\mathcal{A}^\perp_{CP});$$
$$\phi^Q_\parallel = \phi_\parallel + Q\Delta\phi_\parallel; \quad \phi^Q_\perp = \phi_\perp + \frac{\pi}{2} + Q(\Delta\phi_\perp + \frac{\pi}{2}).$$

From the above parameters one can derive triple-product asymmetries $\mathcal{A}^\parallel_T$ and $\mathcal{A}^0_T$ as discussed in Ref. 15:

$$\mathcal{A}^{\parallel,0}_T = \frac{1}{2}\left(\frac{\mathrm{Im}(A_\perp A^*_{\parallel,0})}{\Sigma|A_m|^2} + \frac{\mathrm{Im}(\overline{A}_\perp \overline{A}^*_{\parallel,0})}{\Sigma|\overline{A}_m|^2}\right).$$

The longitudinal polarization in this decay is found to be $0.52 \pm 0.07 \pm 0.02$ as seen in Table 4 and Fig. 2(a); this value is surprising since naive expectations and measurements for $B \to \rho\rho$ indicate a value very close to 1. This confirms earlier measurements by *BABAR* [17] and Belle [18] and is still not understood theoretically. Also shown in Fig. 2(b)-(d) are measurements involving the other quantities determined in the fit.

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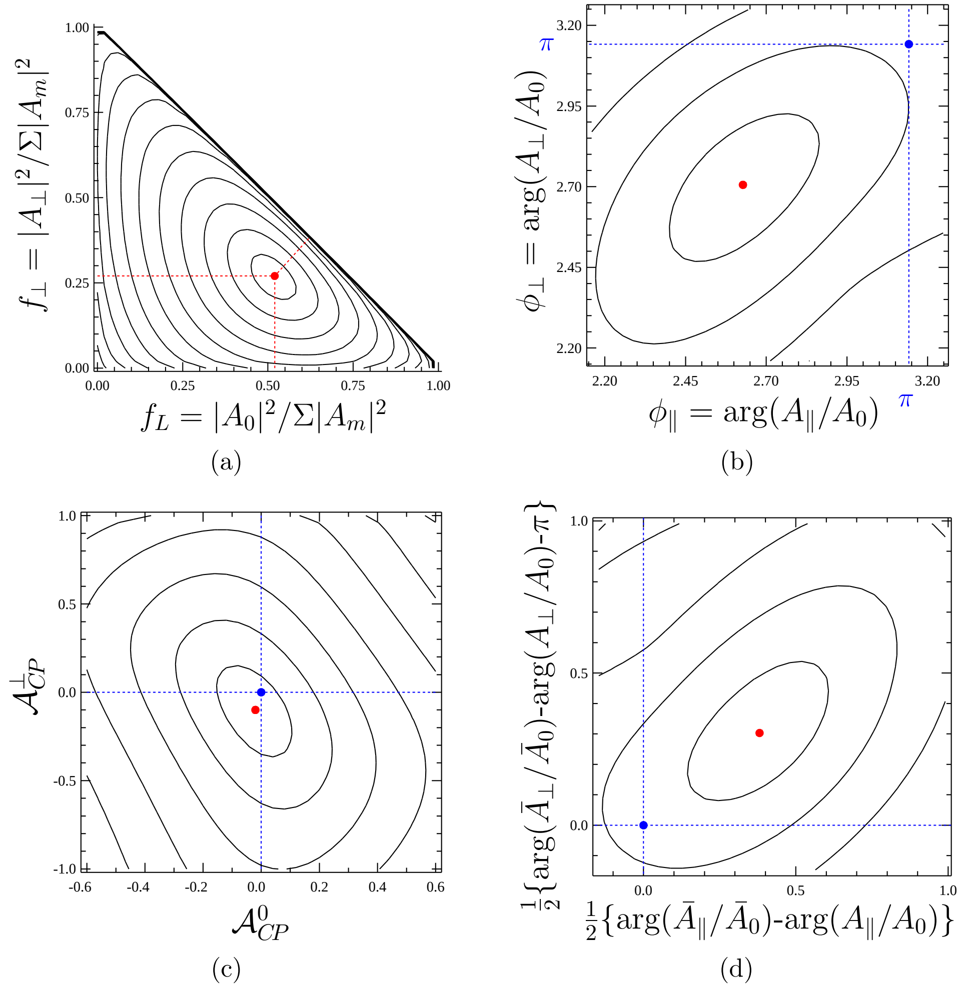

Figure 2: Contour plots with 1σ intervals derived from the fit $-2\ln\mathcal{L}$ distributions for (a) polarization fractions $f_\perp$ and f_L, (b) CP-even and CP-odd transverse phases ($[\pi,\pi]$ point expected if no final-state interactions), (c) asymmetry parameters sensitive to direct CP violation; (d) phases of the triple-product asymmetries that are sensitive to new physics.